Surface hydration and solar wind bombardment of the Moon

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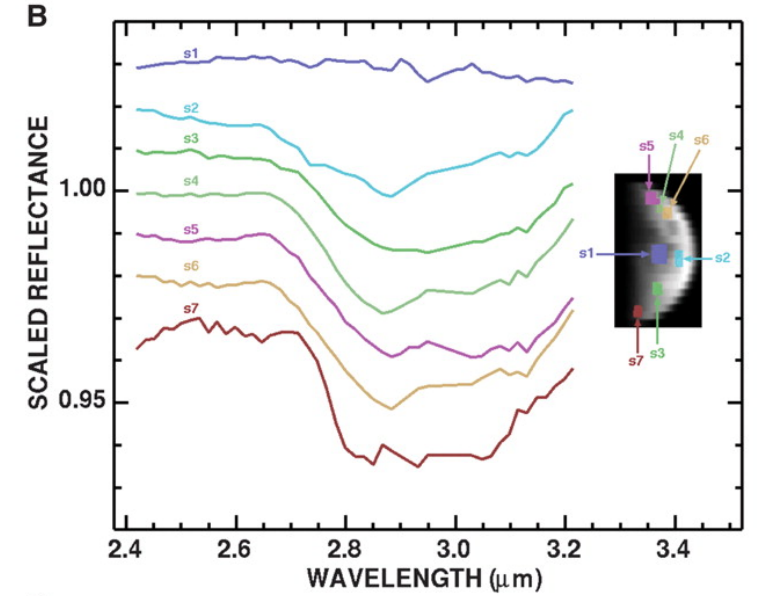
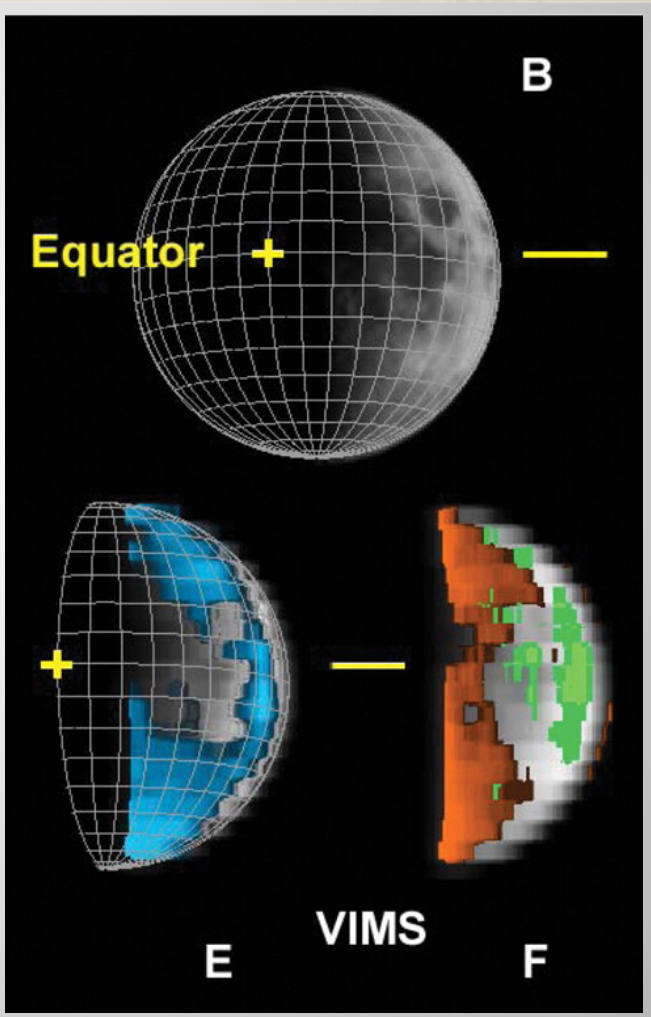
Data Summary

- Cassini VIMS data are consistent with migrating H_2O adsorbed to colder parts of lunar surface
  - H2O

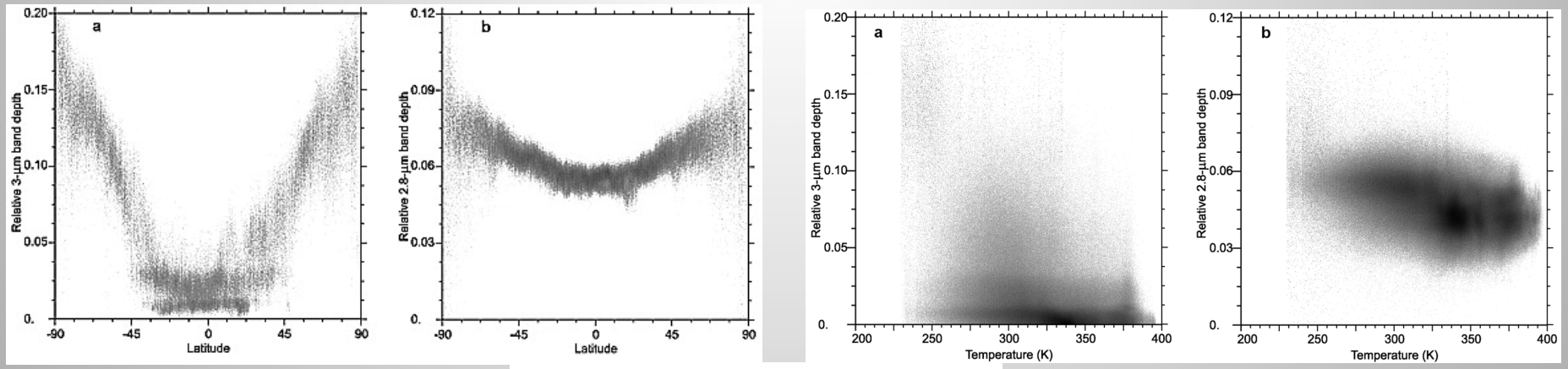


Clark, Science, 2009



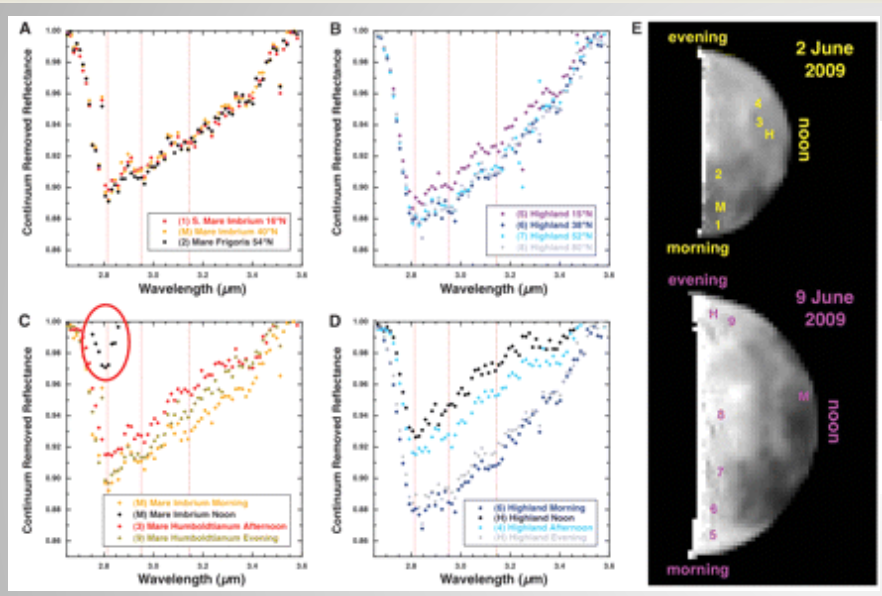
Data Summary

- Chandrayaan-1 M^3 data consistent with H_2O adsorbed on mid-high latitude regions of lunar surface
  - Unclear in McCord et al., 2011 if 3 μm band exists at low latitude near the terminator in M^3 data
  - Similar to Cassini, show decreased band depth on mare.

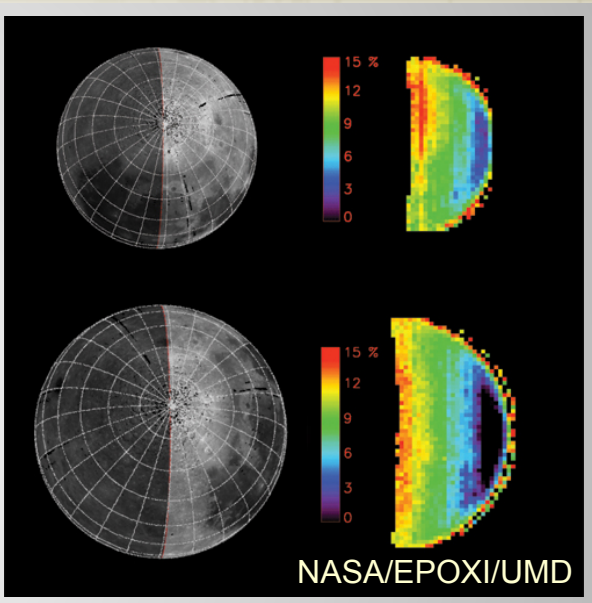


McCord et al., JGR, 2011

Data Summary



Sunshine et al., Science, 2009



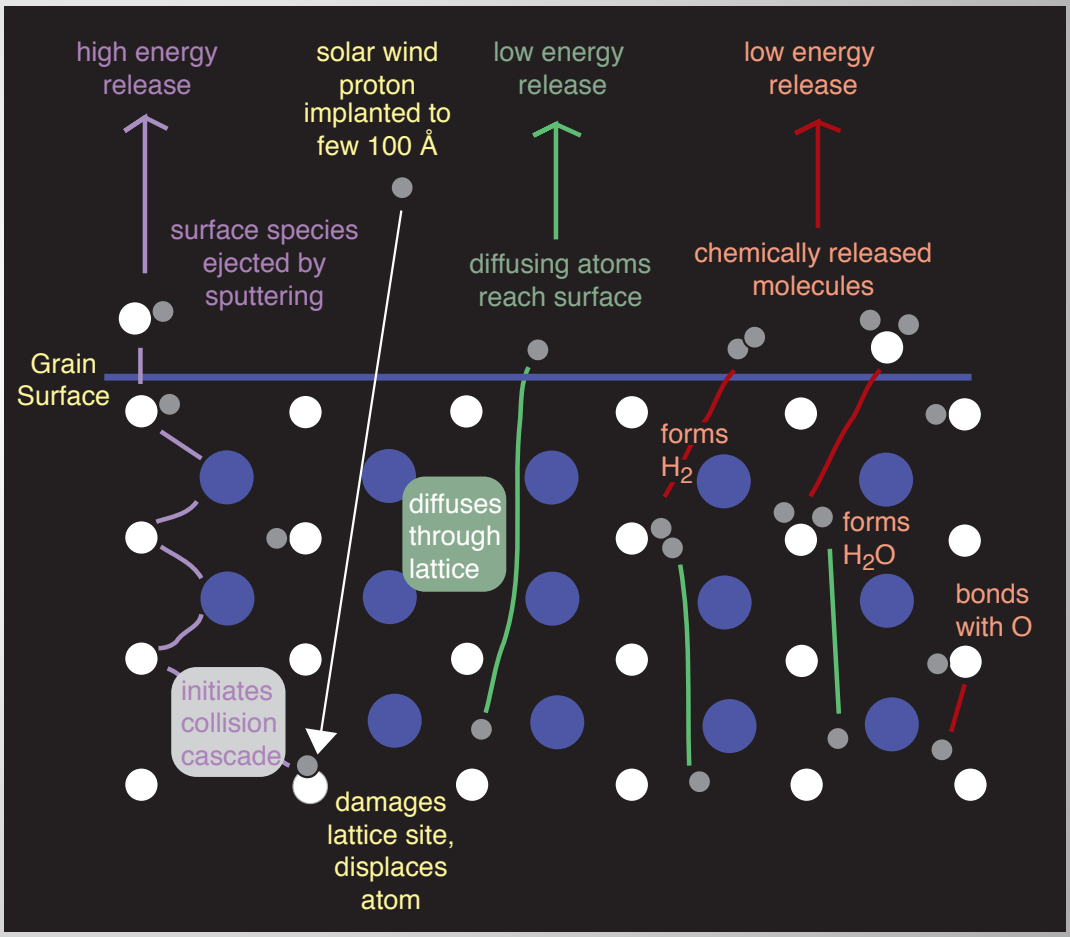
- EPOXI data indicate a change in band depth with incidence angle
- Interesting to note that the Moon was likely in the Earth's magnetotail for 2nd observation (on June 9, 2009)

Data Summary

- **See Amanda Hendrix's talk at 9:45 today**
- Water absorption edge exists in FUV spectrum at 165 nm
- LRO LAMP data are consistent with a latitudinal dependence on the band strength of hydration (greater strength at higher latitude)
- Within a latitude band, there is a dependence of band strength on beta angle (minimum strength at β=0°), especially at low latitude

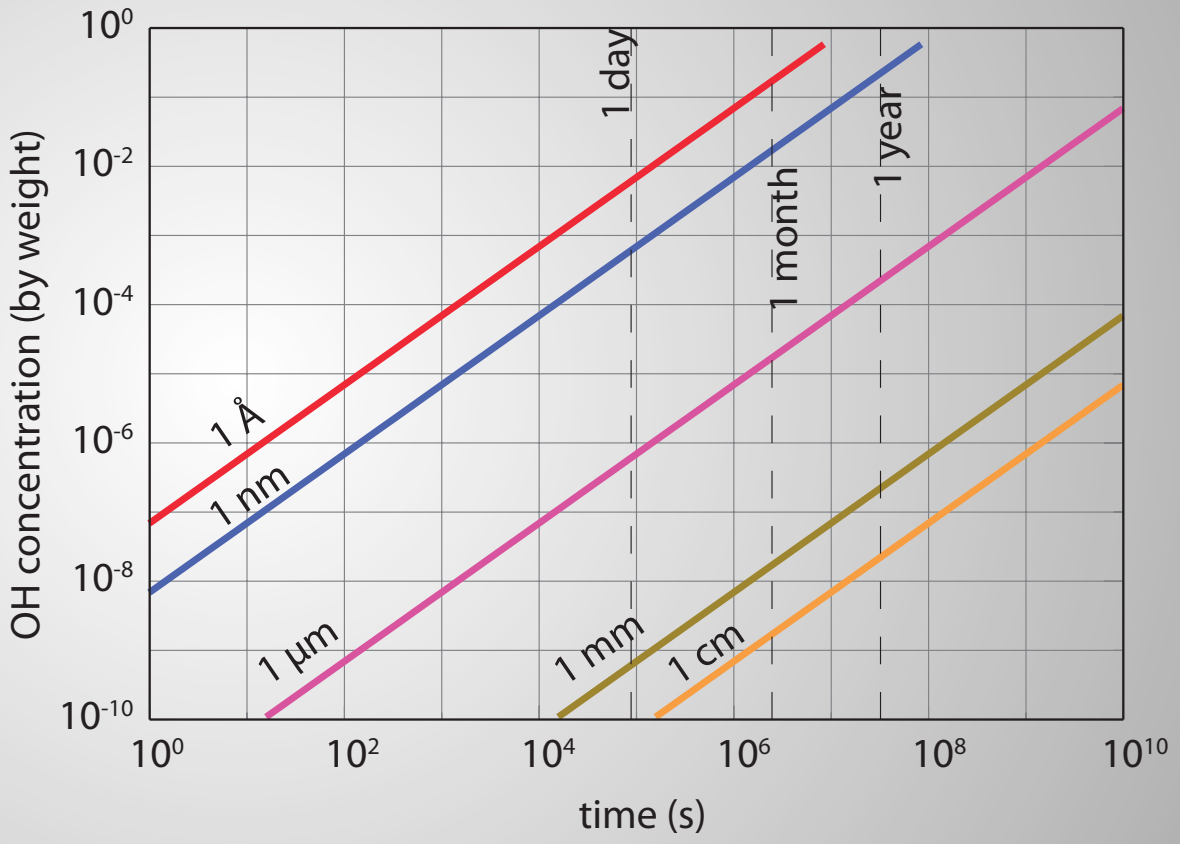
Step 1—Solar Wind Implantation

- Solar wind protons are one possible source of hydrogen for OH/H_2O
  - Protons penetrate ~200 Å
  - Damages lattice
  - Hydroxyl formation



Solar Wind (SW) Delivery Rate

- Available water over a lunation
  - Flux 3e8 $p^{+}cm^{-2}s^{-1}$
  - Fluence 1.8e14 p^{+}/cm^{2}
  - Assume 100% conversion to water
  - Global layer 0.29 Å H_2O
  - For 1000 ppm, 160 Å
  - For 1 µm thickness, 16 ppm

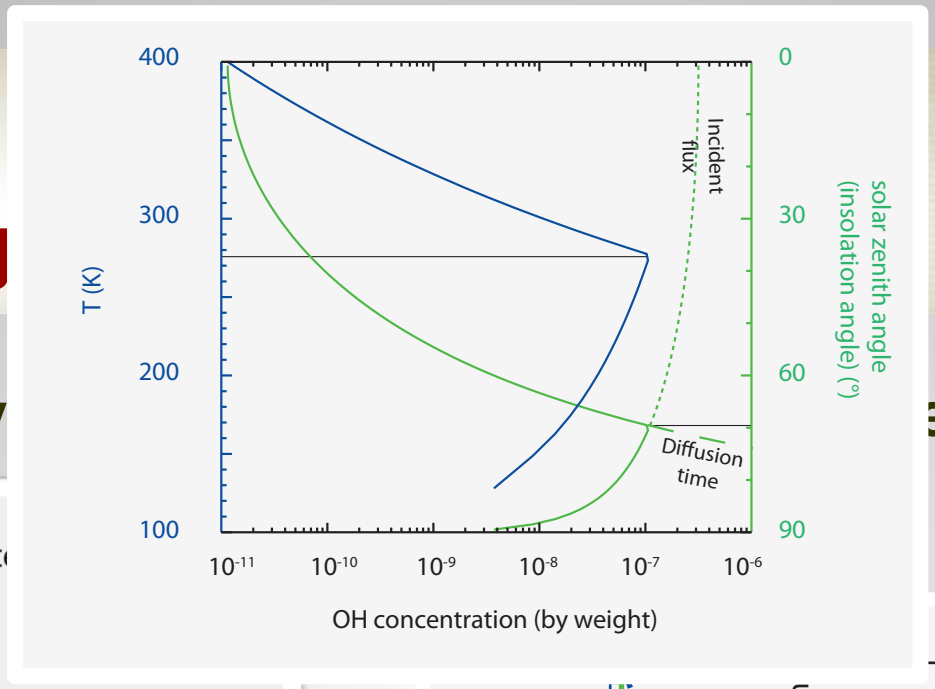


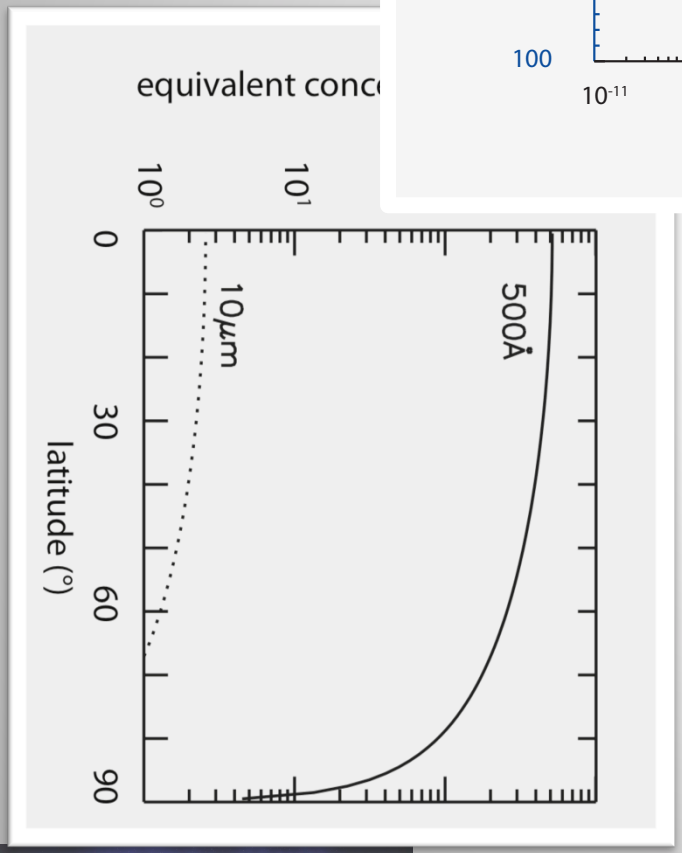
Diurnal Changes—Solar Wind Limits

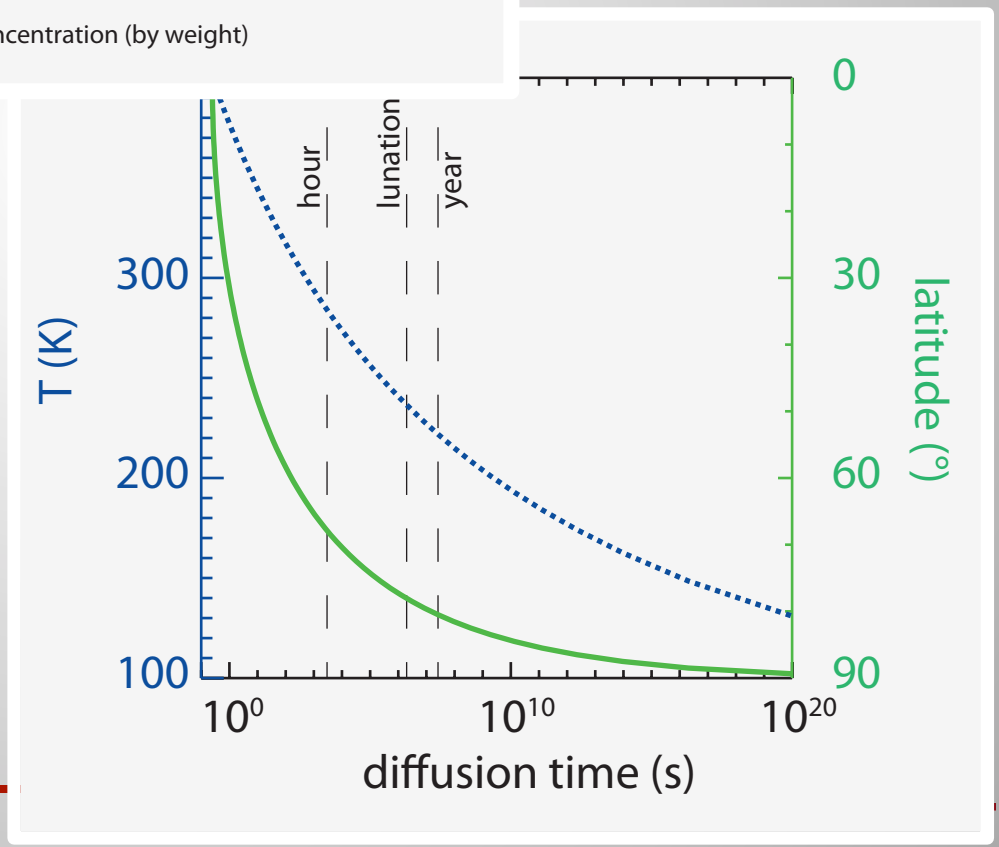
- Changes equivalent to ~100 yrs. worth of solar wind on a diurnal basis would be required to produce an observable diurnal signal
  - This rules out direct implantation of solar wind to explain the variations in band depth with local time
  - Photometric effects may still produce a change in band depth with local time
  - Migration may still produce a diurnal change in band depth

Diffusing

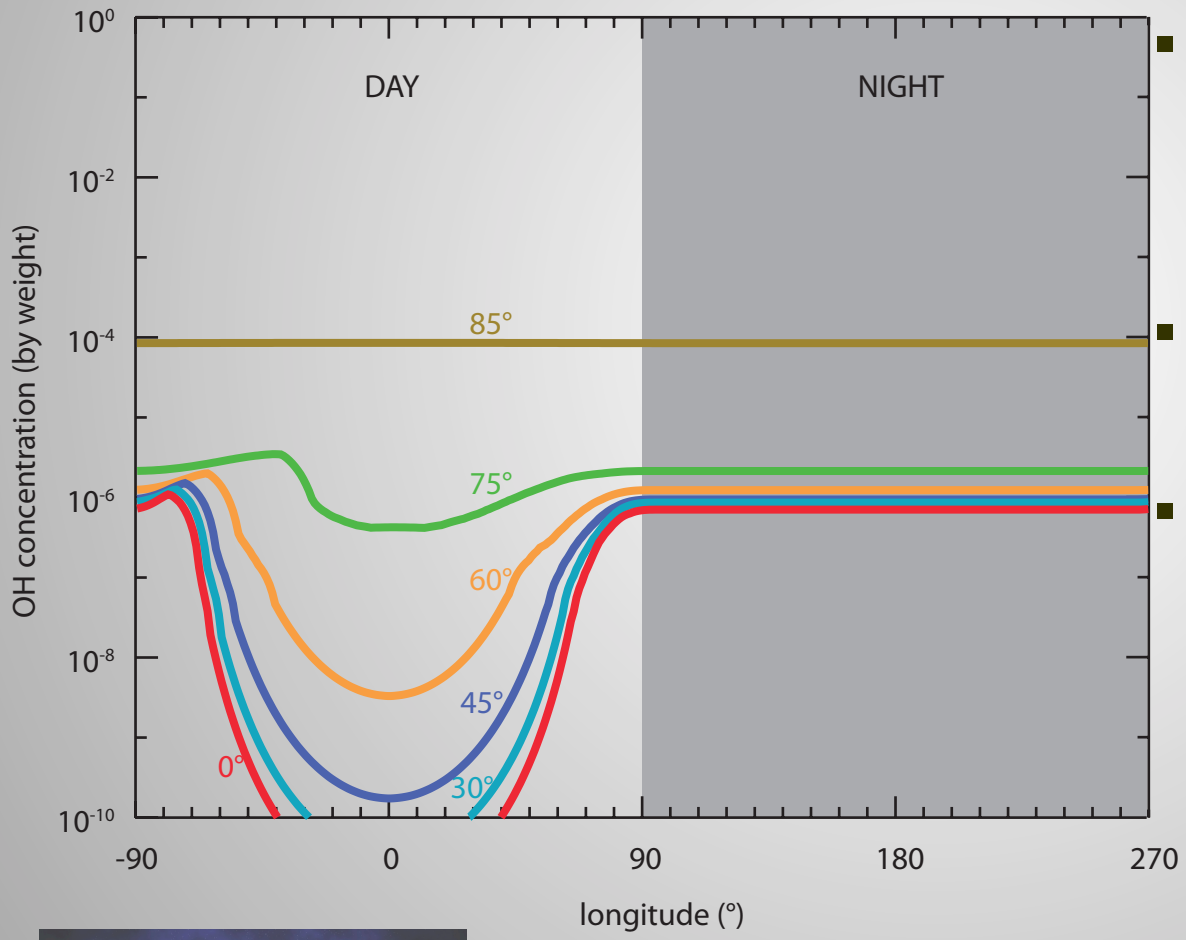
SW delivery







Steady state concentration, diffusing OH



- The balance between influx and diffusing, implanted solar wind protons as a function throughout a lunation
- High latitude—buildup from lunation to lunation
- Low latitude, diurnal signature

DREAM

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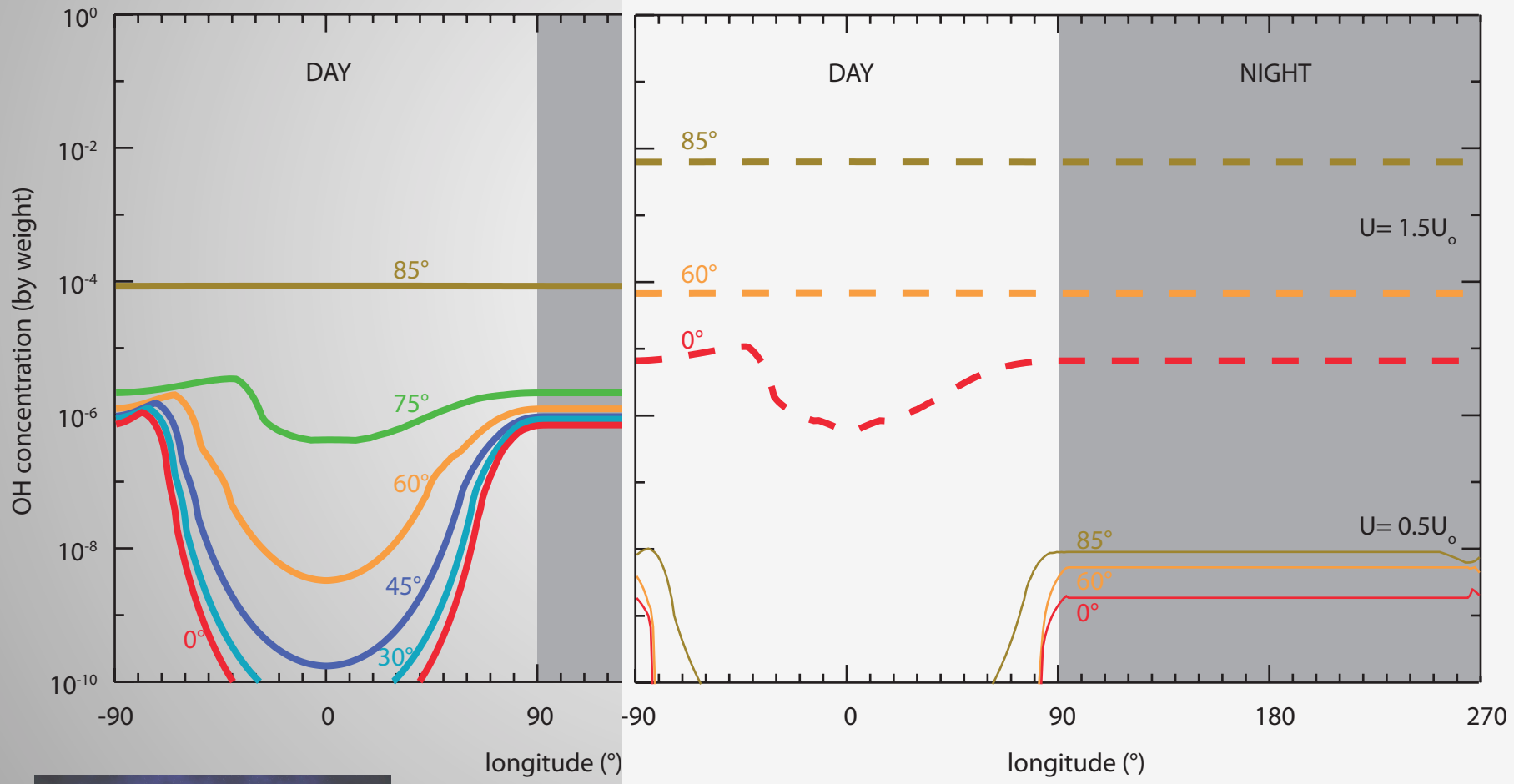
Steady state concentration, diffusing OH

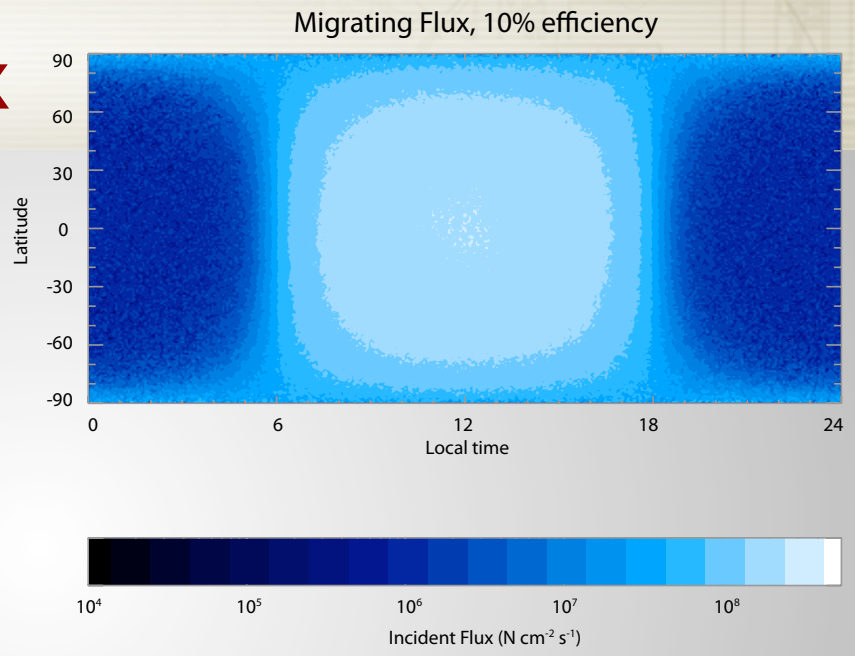


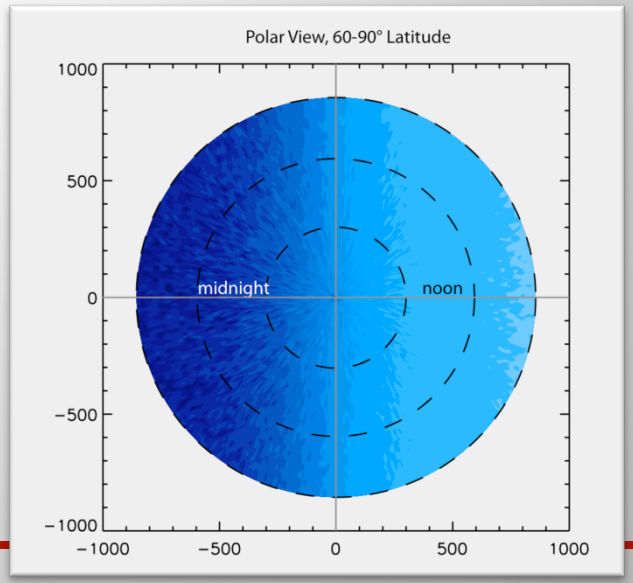
DREAM

APL

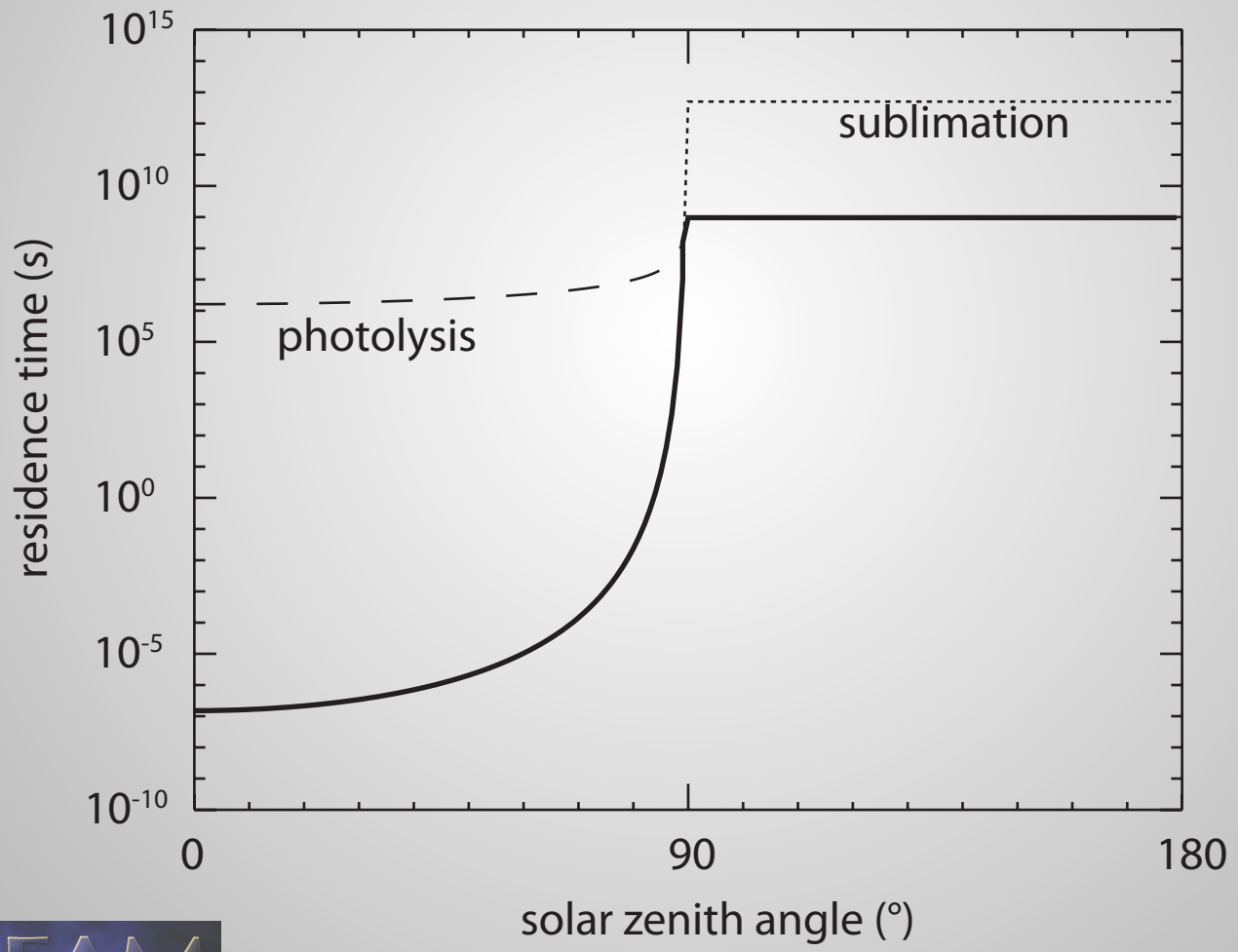
Step 2-Migrating Flux

- Monte Carlo model of migration pattern of H_2O
- Each particle takes an average of 30 hops—boosts flux
- Migration redistributes particles to higher solar zenith angles
- Still have the peak flux at the equator

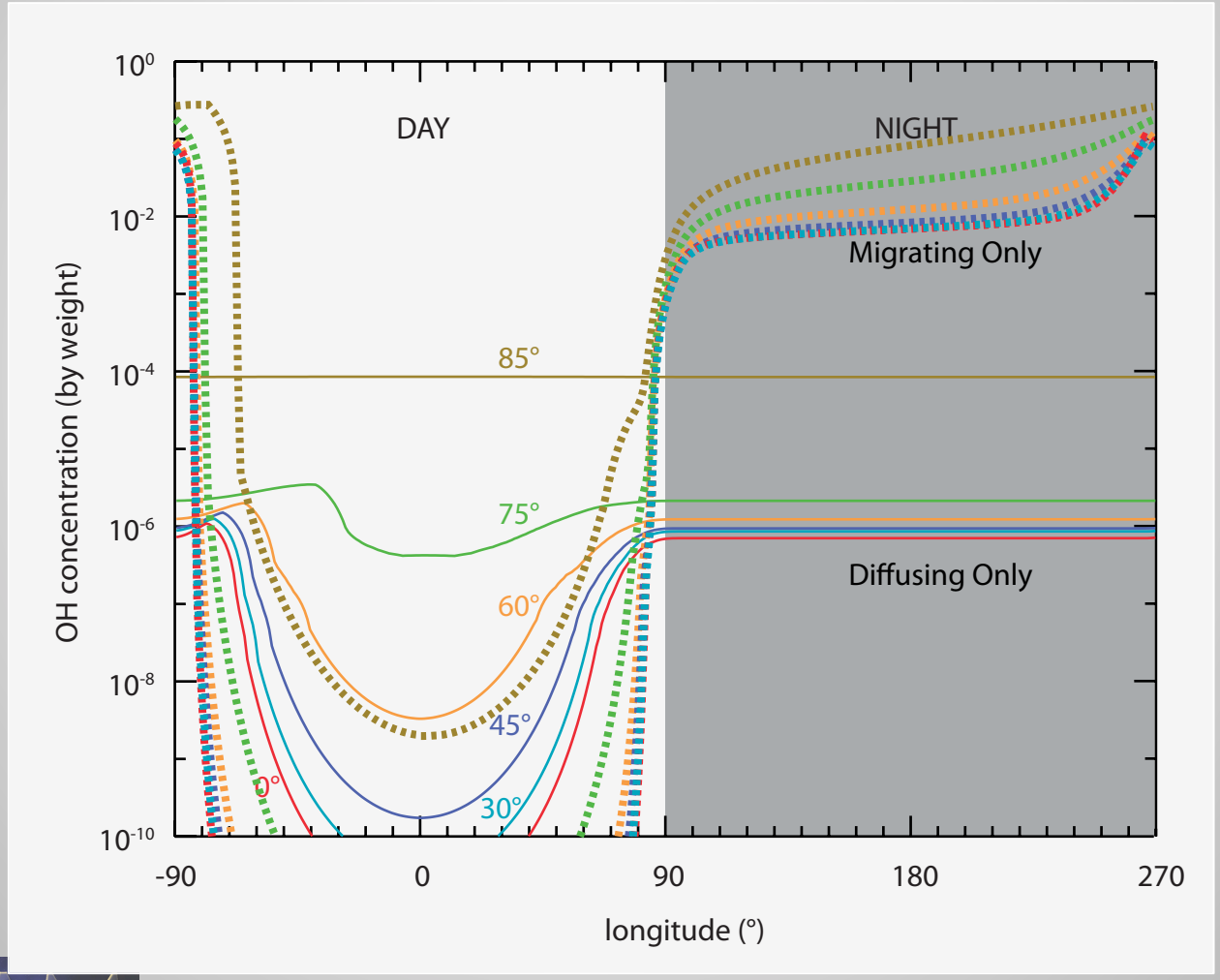


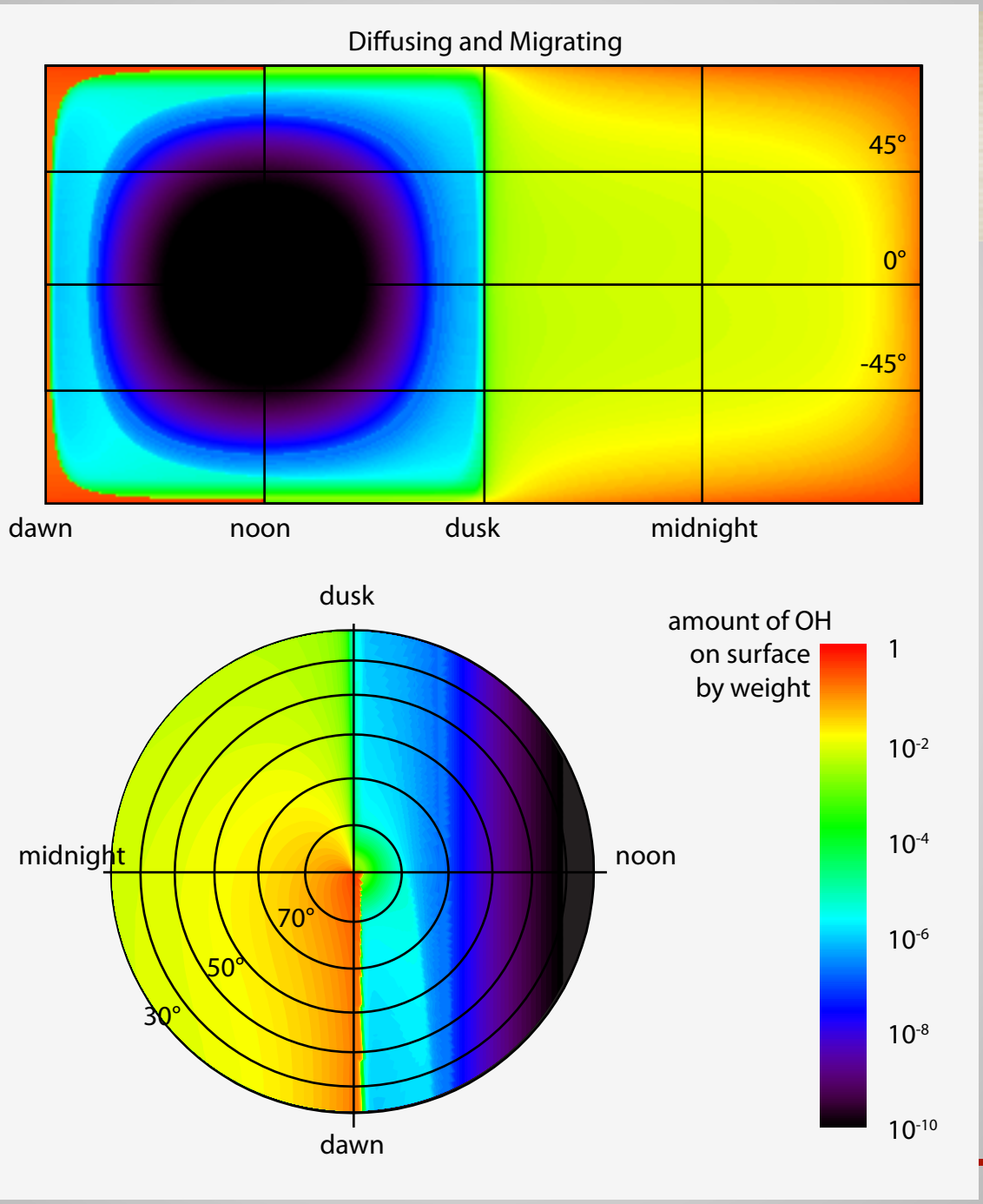


Step 3-Surface Residence



Migrating vs. diffusing concentrations




Diffusing and Migrating
45°
0°
-45°
dawn
noon
dusk
midnight
dusk
midnight
noon
dawn
70°
50°
30°
amount of OH
on surface
by weight
1
10-2
10-4
10-6
10-8
10-10

Conclusions—OH

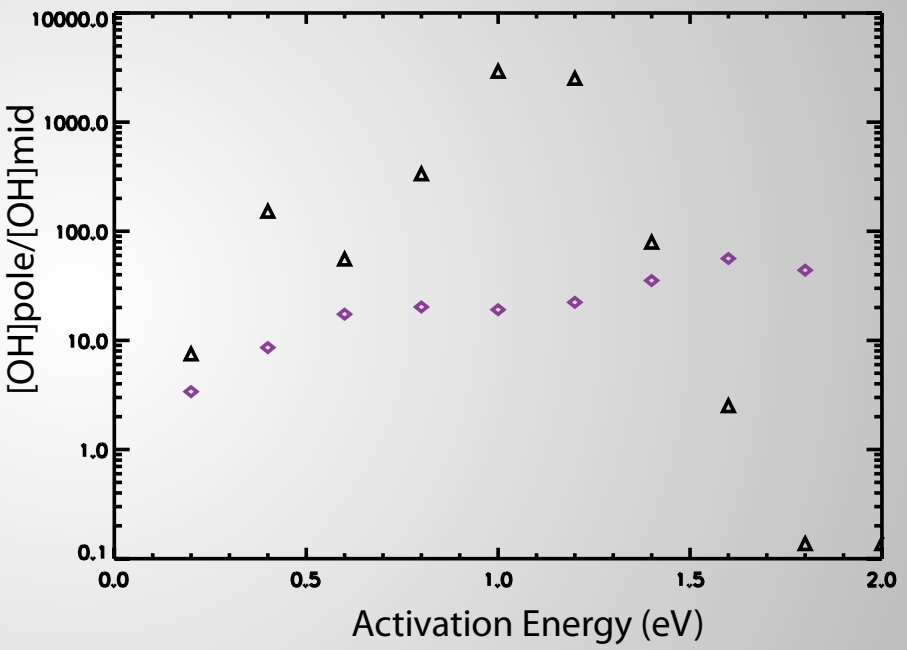
- Incident flux competes with diffusion rate to determine the steady state concentration of OH in the lunar regolith
  - Where diffusion is slower than a lunation, a buildup can occur and the density is pretty flat diurnally
  - Where diffusion is faster than a lunation, some buildup can occur near the terminator, diurnal changes in concentration would occur
  - Solar wind does not provide sufficient source of H to produce observable diurnal variation in OH concentration

Conclusions—H_2O

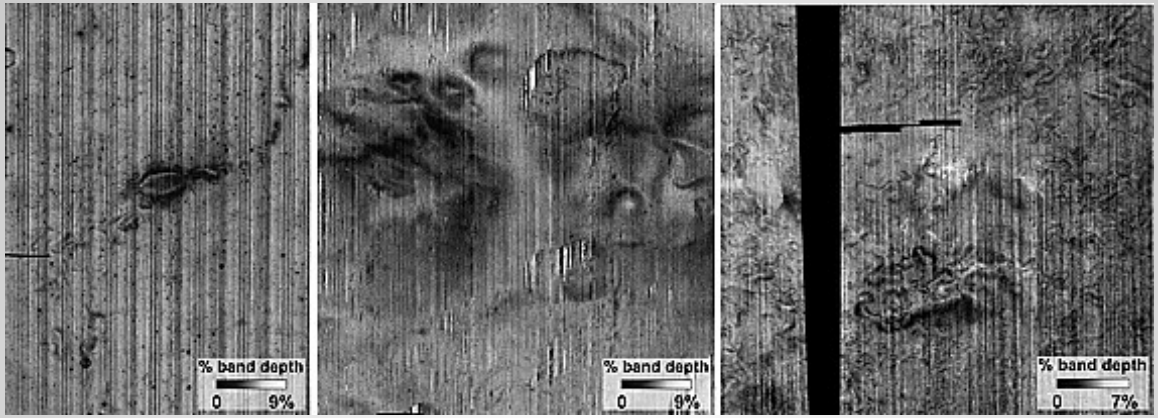
- Migrating water vapor would accumulate on the surface
- Simulations reproduce latitudinal/diurnal distribution
  - Dayside residence determined by sublimation
  - Nightside residence determined by photon stimulated desorption
  - Increase in dayside residence time needed to bring model in agreement with observations, both to get density high enough and to suppress dawn enhancement

Diffusion Simulations

- Varied diffusion parameters
  - Activation energy
  - Diffusion coefficient
- Cannot reproduce an observable diurnal difference
- Produces latitudinal difference



Lunar Albedo Swirls



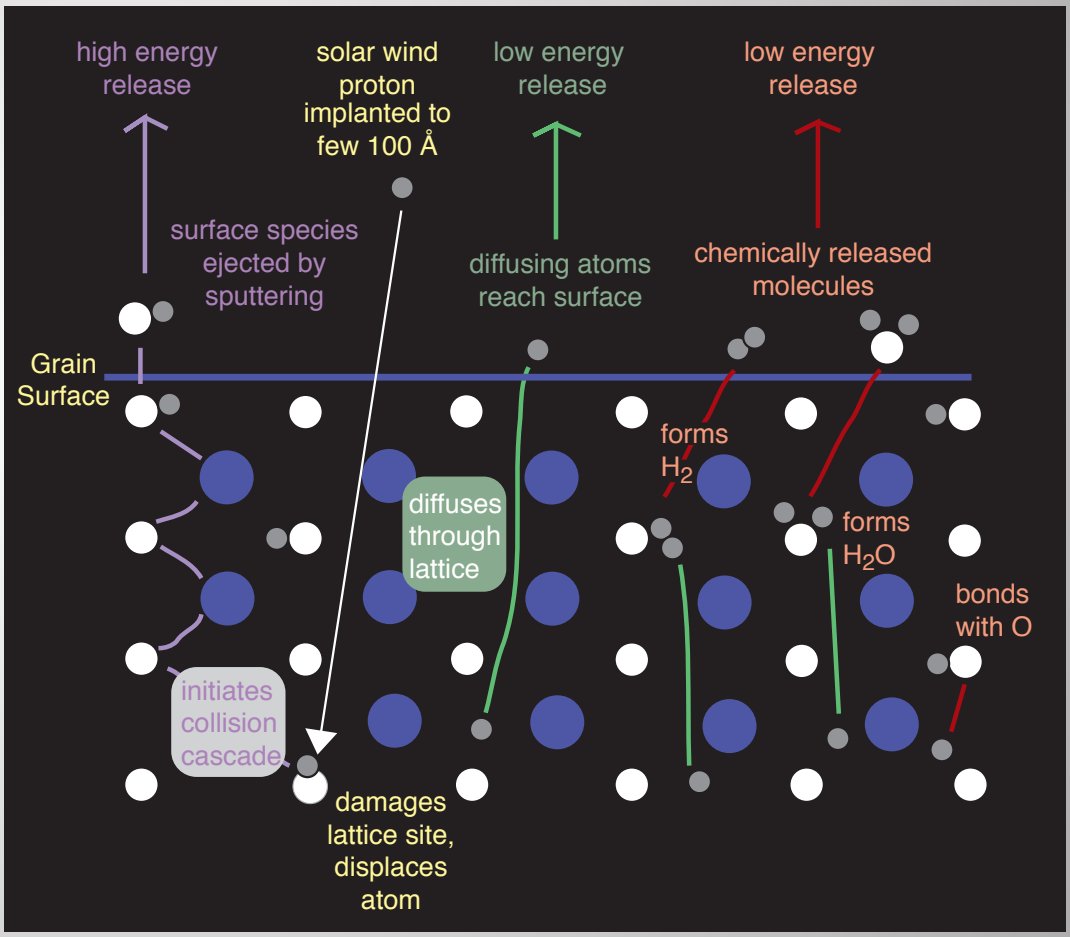
- Regions where magnetic anomalies exist demonstrate interesting characteristics:
  - High albedo swirls
  - Proton reflection (Saito et al., 2008)
  - ENA void (Wieser et al., 2009)
  - Low absorption at 2.8 μm (Kramer et al., 2011)
- Consistent with reduced maturity caused by magnetic fields diverting the incident solar wind flux

Latitudinal Changes—Solar Wind Limits

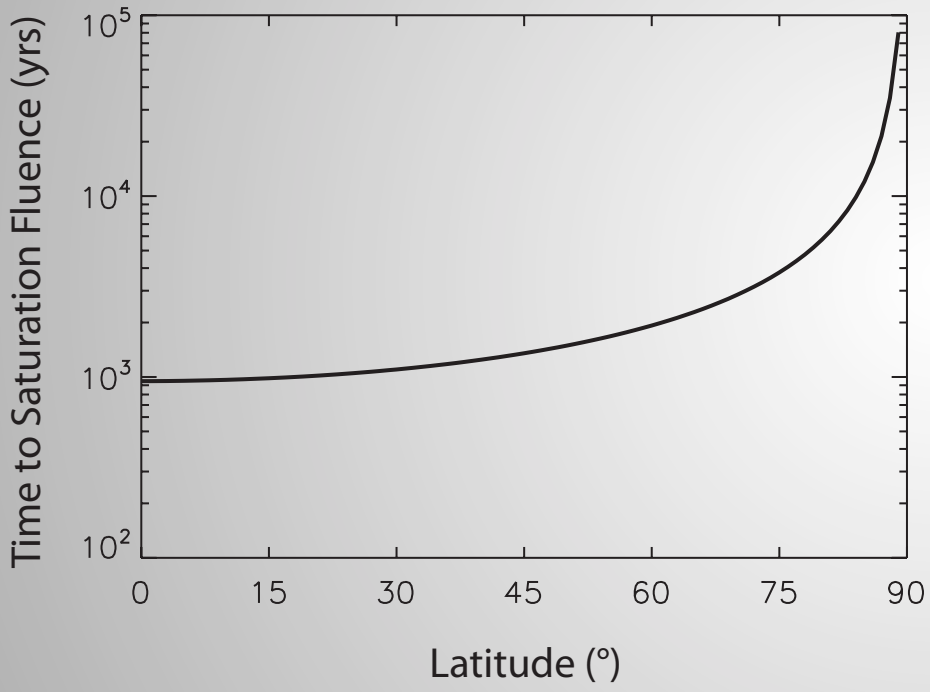
- Time to reach saturation is longer at high latitude than low latitude
- Temperature is colder at high latitude
  - Perhaps a limiting process in the OH concentration is temperature-dependent
    - Diffusion
    - Adsorption

Step 1-Solar Wind Implantation

- Solar wind protons are one possible source of hydrogen for OH/H_2O
  - Protons penetrate ~200 Å
  - Radiation damages lattice
  - Hydroxyl formation
- Saturation levels achieved faster than the regolith turnover time
- Perhaps there are two components, a physisorbed H_2O and a chemisorbed OH.



10-1000 ppm OH—Solar Wind Limits



- Lab indications are that saturation levels achieved for fluence of 10^{18} p^+/cm^2 (Managadze et al., 2011; Blanford et al., 1986)
  - Achieved in ~1000 yr. at equator
- Equatorial regolith samples (Apollo samples) contain implanted solar wind elements
  - Concentration is surface correlated
  - Saturation level is 50-100 ppm H
    - composition dependent
  - If H is in form of OH, this is equivalent to 850-1700 ppm